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Understanding Park Resource Interactions on an Ecological Basis

To carry out its conservation mission, the National Park Service must understand how the resources in its care function as an ecological whole. Until recently this need for scientific resource knowledge was all but overlooked in park management. Thankfully, over the past few decades and especially over the past 15 years, the National Park Service has built and integrated robust science capabilities into park operations. As a result, park science has embarked on a journey toward a more precise understanding

"A science of land health needs, first of all, a base datum of normality, a picture of how healthy land maintains itself as an organism." —Aldo Leopold

of park resource interactions, enabling more objective and sophisticated management decisions. Among the recent changes is implementation of an inventory program for describing the diversity, abundance, and distribution of natural resources

across the National Park System. Now under way in 32 networks of parks, resource monitoring detects change in key indicator resources. Network staffs have begun to determine assessment points or thresholds in declining resource health and formulate new hypotheses to inform management intervention. Studies needed to guide management responses are aimed at understanding stressors, including climate change, the relationships among species and habitats, and many other physical and biological interactions. Data are available for large-scale analyses that will enable us to draw conclusions about park resource trends, with potential for greater understanding of patterns on multipark and even regional scales. The network approach to monitoring design and reporting, which involves multiple parks with similar biogeographic characteristics, is proving efficient. Collaboration is on the rise for sharing stewardship responsibilities and increasing the rigor of science. The following articles suggest that the National Park Service is beginning to understand the complex systems under its care.



Sixty-one eastern parks coordinate forest monitoring

By Brian R. Mitchell and Matthew R. Marshall

FORESTS, THE DOMINANT ECOSYSTEMS OF THE

eastern United States, are intricately tied to the health of our national parks. Consequently, understanding forest health is fundamental to knowing the condition of park resources. Forest monitoring programs are critical to gaining this knowledge and many are in existence today. Unfortunately, these programs often use different definitions and methods, making comparison of their results difficult. Thanks to coordination among a number of national parks and monitoring programs in 2006, some agreement on forest monitoring approaches is emerging, which bodes well for our understanding of forest health.

In the eastern United States, a variety of state, federal, and nongovernmental organizations operate dozens of vegetation monitoring programs. Results have been used to guide conservation, research, and management actions, often at a local scale. Although some effort at alignment among these programs has been made in recent years, most programs operate independently. The lack of coordination has resulted in conflicting terms and definitions, redundant data collection, inconsistent field protocols, and, sometimes, flawed survey designs. A coordinated approach would allow meaningful and valid comparisons among programs and regions and, potentially, significant cost savings.

Several eastern national parks and monitoring networks have joined forces to ensure that their protocols for tracking forest health are compatible with each other and with the USDA Forest Service's Forest Inventory Analysis and Forest Health Monitoring programs. Participants include four National Park Service (NPS) regions, with eight Inventory and Monitoring (I&M) networks, and three prototype parks. Parks within an I&M network have similar environmental characteristics. Prototype parks are select parks where protocols for inventory and monitoring are developed. Sixty-one national parks (23% of the parks in the Inventory and Monitoring Program) are participating. They belong to the Appalachian Highlands, Cumberland Piedmont, Eastern Rivers and Mountains, Great Lakes, Mid-Atlantic, National Capital Region, Northeast Coastal and Barrier, and Northeast Temperate networks; Cape Cod National Seashore (Massachusetts), Great Smoky Mountains National Park (Tennessee and North Carolina), and Shenandoah National Park (Virginia) are also participating as proto-



This monitoring plot at Manassas National Battlefield Park, Virginia, exhibits a healthy forest with good regeneration and an understory of primarily native species, which set it apart from the overbrowsed condition of the rest of the park.

types. The monitoring programs range from those that have been collecting forest data for years (the three prototype parks) to those that began (or will begin) installing monitoring plots in 2006 and 2007.

The participating programs had two meetings in 2006 to discuss, evaluate, compare, and standardize their respective monitoring protocols. These meetings have resulted in much closer coordination of protocols among networks and parks, and in particular have resulted in the adoption of similar definitions, and agreement on size classes, that will be compatible across programs. This level of agreement will greatly simplify meta-analysis of monitoring results, and will allow the different programs (which often monitor resources in small park units) to pool results to



This part of the forest at Chesapeake and Ohio Canal National Historical Park near Great Falls, Maryland, has poor tree regeneration and an understory dominated by Japanese stilt grass, an invasive species.

examine broad forest health trends across much of the eastern deciduous forest ecosystem. An additional meeting in January 2007 provided participants with program updates and continued discussions about coordination among programs. Participants expressed interest in the forest ecological integrity scorecard being developed by the State University of New York's College of Environmental Science and Forestry and the Northeast Temperate Network. Future meetings will work on finding common metrics that can be used in the scorecard and adapting the approach for application beyond the Northeast Temperate Network.

In addition, after the January 2007 meeting, the National Capital Region Network gathered forest plot data from nearly 2,500 plots in 50 national parks of the participating networks in order to examine the incidence of exotic plant species. The data came from long-term forest monitoring plots established by the networks and parks as well as from plots established by the NPS Vegetation Mapping Program, and the analysis served to demonstrate the potential for meaningful cooperation. This broad survey found that 48% of plots had no exotic species; however, on average there were 2 exotic species per plot and a mean of 24 exotic plant species per park. The most common of the 290 exotic species detected in these parks were Japanese honeysuckle (*Lonicera japonica*), Japanese stilt grass (*Microstegium vimineum*), and multiflora rose (*Rosa multiflora*); each of these plants was found in more than 300 plots. This is the first of what network partici-

pants hope will be many analyses that will examine the health of forest resources in eastern parks.

The participants in this series of coordinated forest monitoring meetings feel that the interactions have been valuable, and they plan to continue this collaboration. The existing and pilot monitoring programs have benefited from additional peer review and assistance that have strengthened the scientific rigor of their programs. Networks in the planning stages of their monitoring efforts are experiencing considerable cost savings in protocol development by using existing protocols that incorporate methods they helped to develop. Future benefits may include cost savings in data analysis and reporting and in sharing field crews (and crew training) between programs. As more of the eastern networks implement long-term monitoring in the coming years, network participants anticipate many additional rewards from our collaborative forest monitoring efforts. ■

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Twenty-four years of Great Lakes lichen studies provide park biomonitoring baselines

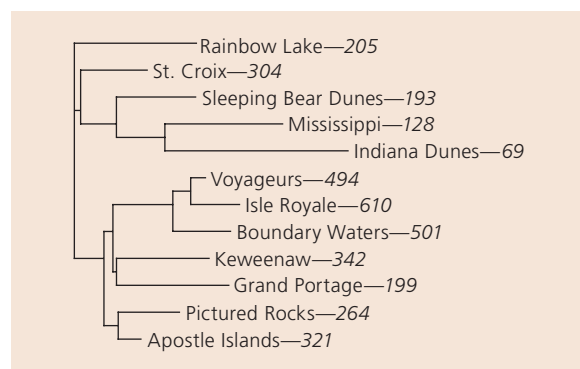
By James P. Bennett

FOR THE PAST 24 YEARS, BIOLOGISTS HAVE studied lichens in the Great Lakes national park units in considerable detail (see map), including floras and chemical element surveys, for biodiversity and air quality assessments. They have studied lichens because they are sentinel species indicating ecosystem health, and because they are excellent biomonitoring and bio-indicator species of air quality. These studies have been funded by individual parks, the NPS Air Resources Division, and the U.S. Geological Survey.

It is well-known that lichen diversity increases with latitude in this region, and this is seen in the numbers of species in the parks (see dendrogram). The five areas in



A species that grows exclusively on rocks, the elegant sunburst lichen (*Xanthoria elegans*) is found in 56 U.S. national parks. In the Great Lakes area it has been documented at Apostle Islands, Isle Royale, Keweenaw, Saint Croix, and Voyageurs as part of ongoing lichen studies.



The dendrogram shows the relationships among the park/forest areas based on the diversity of lichen species present in each area. The sum of the lengths of all horizontal lines between any park/forest pair is a measure of how similar or dissimilar the areas are based on lichen species. The number of lichen species inventoried in each park/forest follows the area's name.

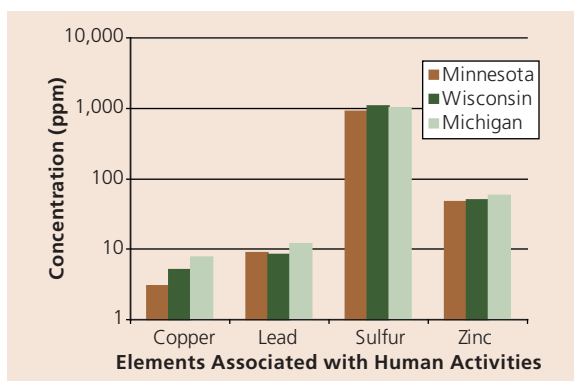
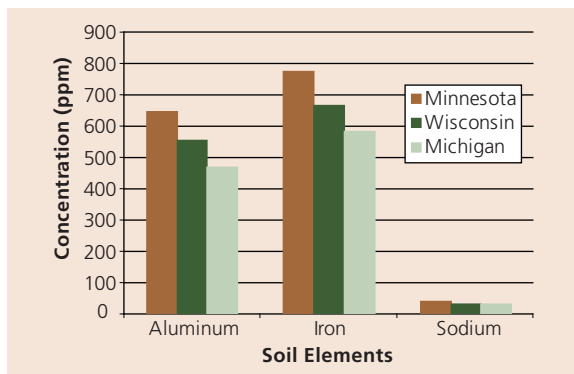


Lichen study areas in the Great Lakes region.

the top group are located south of 46°N latitude, are either associated with rivers or have very little rock substrate (which is usually rich in lichens), and average 180 species per park. The seven areas in the bottom group (five are in the Lake Superior basin) are north of 46°N and average 390 species per park, more than twice as many as in the other group.

Indiana Dunes National Lakeshore has the fewest lichen species, is the most southern and most heavily influenced by human activities, and is the least similar to any other park. However, along with Apostle Islands National Lakeshore and Grand Portage National Monument, it also has two unique species. The relatively high number of single occurrences of species of lichens of all these areas is probably greater than that of the vascular plants, and they deserve consideration for special management and protection.

Investigators have analyzed more than 35,000 elemental chemistry records from lichens of 10 of these areas. Using the data for the four most common lichen



Mean concentration of chemical elements in four common lichen species sampled in 10 national park/forest areas, by state, 1982–2006.

species, they have found that some chemical elements increase and some decrease in parks from west to east (see graphs).

The soil elements aluminum, iron, and sodium decrease from west to east, probably because of increasing distance from blowing dust of the Great Plains. However, elements associated with human activities—copper, lead, sulfur, and zinc—increase from west to east with increasing proximity to eastern population centers. Investigators have also examined chemical patterns through time and have found, for example, that lead concentrations in lichens, which averaged from 17 to 23 parts per million (ppm) in the early 1980s, have decreased significantly to levels below 6 ppm in the mid-2000s in the three-state area.

In addition, the studies have identified elemental differences among parks and species using discriminant analyses. Differences among species appear to be

The relatively high number of single occurrences of species of lichens of all these areas is probably greater than that of the vascular plants, and they deserve ... special management and protection.

greater than differences among parks. Biomonitoring of air quality in parks must therefore be done with certain species to control the precision and accuracy of data over time and space.

Both the elemental data and the species presence data are now available on Web sites of the U.S. Geological Survey: *NPElement* at www.nwhc.usgs.gov/our_research/np_element.jsp (more than 70,330 data points) and *NPLichen* (more than 29,000 data points) at <http://www.ies.wisc.edu/nplichen/>.

Investigators continue their detailed analyses of many spatial and temporal patterns in this region. Their greatest challenge is interpreting results for the region as a whole. Parks are not distributed geographically in such a way that strong regional inferences can be made, but conclusions about the areas themselves will be possible. The lichen richness across these areas is greater than that of any of the states they are in, and the high degree of single occurrences of certain lichen species among them suggests that their special area protection has been responsible for this. Investigators hope to emphasize this in the future so that area managers will have more information to maintain and improve protection practices. Finally, the establishment of biomonitoring baselines for these areas has been enhanced by being able to compare individual areas with others, thus improving spatial and temporal trends results and interpretation. ■

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Aquatic insects inventoried in Appalachian Highlands and Cumberland Piedmont network parks

By Jason Robinson, Charles R. Parker, and Nathan J. Sanders

THE SOUTHEASTERN UNITED STATES HAS THE highest biodiversity of aquatic insect species of any region in North America. Approximately 1,400 (40% of all) North American aquatic insect species occur in the Southeast. Data from a variety of sources (the All Taxa Biodiversity Inventory in Great Smoky Mountains National Park [North Carolina and Tennessee], monitoring programs in Big South Fork National River and Recreation Area [Tennessee] and Mammoth Cave National Park [Kentucky], and academic studies in Little River Canyon National Preserve [Alabama] and Shiloh National Military Park [Tennessee]) suggest that the national parks in the region harbor a significant subset of these southeastern aquatic insect species. In 2005, scientists and university researchers began a three-year study to inventory the aquatic insect fauna of the 17 parks of the Appalachian Highlands and Cumberland Piedmont monitoring networks. Funded by the USGS–Natural Resource Preservation Program, the project’s 2006–2007 focus is on completing the fieldwork to fill in spatial and temporal gaps in coverage throughout the parks, and on sampling unique habitats and taxa of particular interest.

To design this study researchers contacted the National Park Service (NPS) for approval and assistance. Then, relying on the NPS “networks” for permits, Geographic Information Systems data, suggestions on sampling locations, and overall logistics, they began the exhaustive inventory project. Drawing upon combined resources and technical staff, national parks across the nation have formed regional networks to better monitor and inventory ecosystems and identify critical indicators of ecological health, called vital signs. The goals of this study are to determine the significance of the national parks of the Appalachian Highlands and Cumberland Piedmont networks as reserves for aquatic insects, and to make recommendations to the management of each park for the long-term conservation of their fauna. Specific objectives include conducting an inventory of the EPTO (Ephemeroptera, mayflies; Plecoptera, stoneflies; Trichoptera, caddisflies; and Odonata, dragonflies and damselflies) fauna of each park and providing the parks with assessments of their aquatic insect fauna. Assessments will include national and state conservation status for each species, perceived threats to the habitats where species of concern are found, and the relationship of park fauna to southeastern fauna as a whole. Other objectives

include providing parks with information on the identification, distribution, life history, and biology of each aquatic species; contributing data to the NPS inventory and monitoring databases; and testing ecological and evolutionary hypotheses about the development and maintenance of this amazing diversity.

In 2006, researchers made more than 200 collections in 17 network parks. In each park they discovered species not previously known in that park. In at least 7 parks, they discovered species new to science. Researchers also discovered several species that are endemic, rare, and poorly known. In addition they demonstrated that some species thought to have highly restricted distributions are, in fact, much more widely distributed. The 4 parks of the Appalachian Highlands Network have more species, genera, and families of aquatic insects than the 13 parks of the Cumberland Piedmont Network. Of the 233 species collected in 2006, however, only 68 (29%) are shared between the networks. These findings have a biological importance independent of the management issues underlying the study and contribute to a better understanding of evolutionary, ecological, and biogeographic relationships among aquatic organisms. The findings will, in turn, provide information on practical management issues.

A regional assessment of threats to aquatic biodiversity is impossible until an inventory of these systems is performed. Since a complete inventory is impractical at the regional scale, this study provides a preliminary analysis of



Researcher Jason Robinson sets up an ultraviolet light trap along South Knob Creek at Abraham Lincoln Birthplace National Historic Site in Kentucky. A photocell turns the light on when the sun sets and off when the sun rises, allowing unattended operation.



A larva of a caddisfly in the genus *Polycentropus* (Trichoptera: Polycentropodidae) collected in North Carolina on the Blue Ridge Parkway. Larvae construct a loose, disorganized web of silk and use it to capture prey, much in the manner of terrestrial spiders.



Rodney Martinez, a biologist with Cumberland Gap National Historical Park (Kentucky, Tennessee, and Virginia), examines insects collected in the park.

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regional biodiversity conservation potential in national parks. If habitat degradation and fragmentation continue at current rates outside of the parks, researchers will at least have described the aquatic insect biodiversity now present in these national parks.

The discovery of rare and endemic taxa raises more questions, particularly concerning the amount of effort required to completely inventory a park. Fortunately there is an ever-increasing array of statistical approaches to address the extent of undersampling. Although these tools can provide an estimate of species that might be captured if a park were completely sampled, they do not tell managers which species have yet to be detected. Only exhaustive collecting can accomplish this goal.

As a whole, this project has important conservation, management, ecological, and evolutionary implications. First, researchers can continue to locate rare species and those that are new to science. This infor-

mation will clearly be important for management decisions within these national parks. Second, the work can pose new questions regarding the ecological factors that limit the number of species found at any one place at any one time, an age-old issue that has been little explored in aquatic insects at this spatial scale. Finally, with the advent of modern molecular tools, this extensive inventory and monitoring research can aid in untangling the complex evolutionary history of aquatic insect species in the southeastern United States. ■

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Coral reef monitoring offers case study for identifying monitoring assessment points

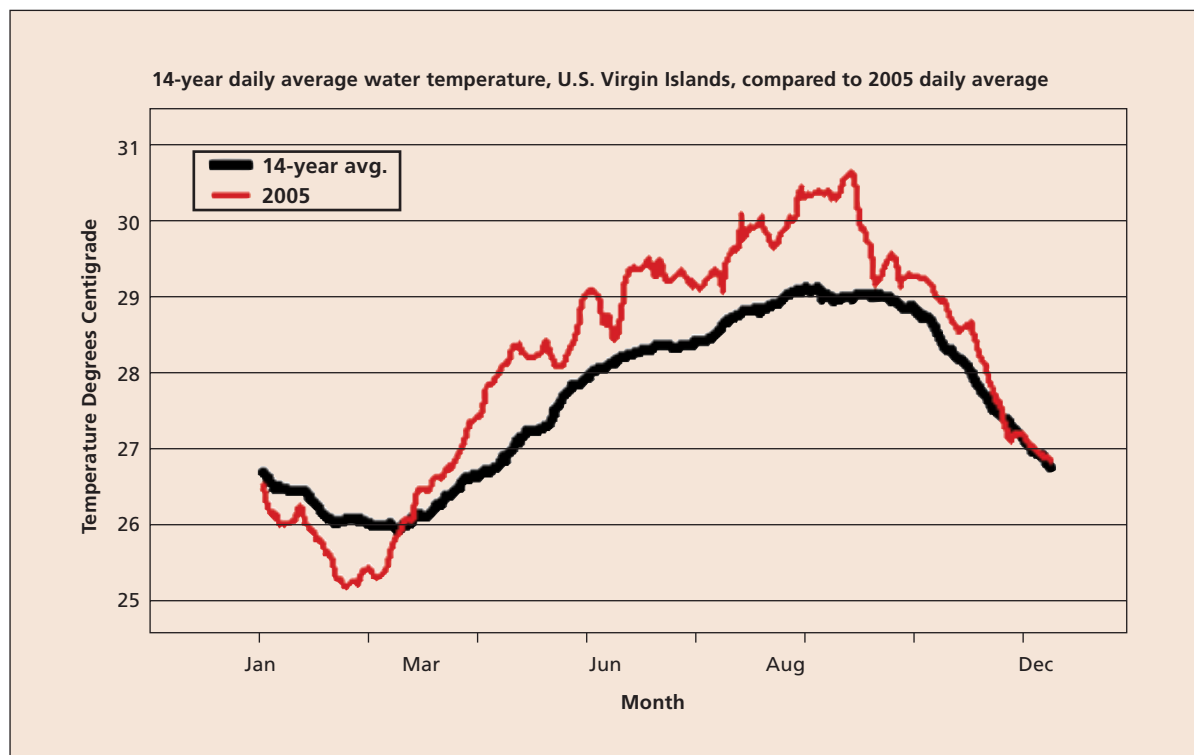
By Matt Patterson

NATIONAL PARKS ARE PLACES OF SPECTACULAR

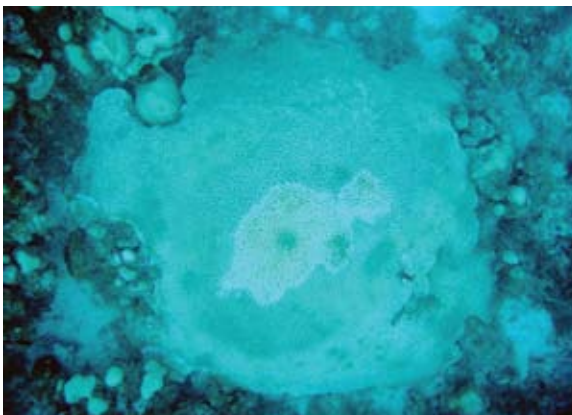
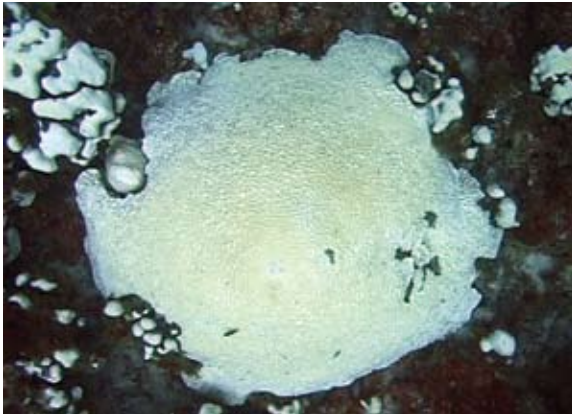
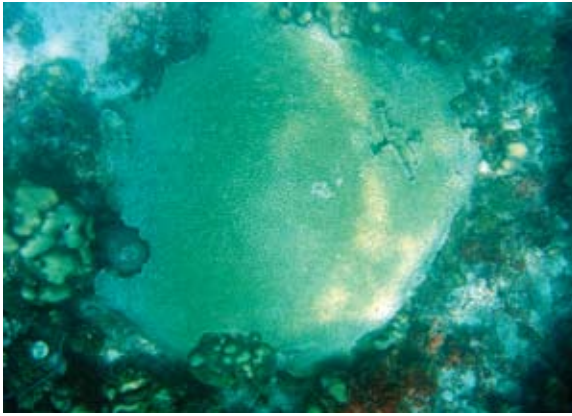
beauty, but beauty is not a sufficient indication of the condition of park resources. Park managers need accurate information about the plants, animals, and natural systems in their care in order to make sound management decisions and undertake adaptive management activities to respond to adverse changes. For this reason the National Park Service's (NPS) Vital Signs Monitoring Program organizes approximately 270 park units into 32 monitoring networks to conduct long-term monitoring for key indicators of ecosystem health, or vital signs. The NPS Vital Signs Monitoring Program is grappling with identifying assessment points for each vital sign. Assessment points establish benchmarks that are used to alert park managers to changes in resource conditions that may suggest the need for different management prescriptions. In 2005 and 2006, changes in ocean temperatures off the U.S. Virgin Islands affected coral reefs in two national park units and provided NPS scientists a case study for identifying an assessment point for coral reef monitoring.

In 2005 and 2006 the South Florida/Caribbean Inventory and Monitoring Network faced an unprecedented increase in oceanic water temperatures; over this period water temperatures exceeded the previous 14-year average in the U.S. Virgin Islands. These higher temperatures were driven primarily by 2005 weather patterns that caused tropical storms to miss the U.S. Virgin Islands. Without storm-induced cloud cover and high winds to mix the ocean, water temperatures rose. This elevation led network staff to increase monitoring of coral reef resources at Virgin Islands National Park and Buck Island Reef National Monument in order to detect the temperature-induced stress responses of the coral reef community.

As water temperatures rose from April through September 2005, monitoring teams visited a subset of high, stony coral reef sites every few months to track the extent of coral bleaching. Under normal conditions, scientists would visit these sites annually, but in 2005 they were alerted to the need for more frequent monitoring



Bleaching occurs when the coral animals experience a 2- to 3-degree Centigrade increase in water temperature that is sustained for days to weeks. As water temperature rose in 2005, network staff monitored transects at Virgin Islands National Park and Buck Island Reef National Monument more frequently, tracking the progression of bleaching to an eventual 90% of stony corals along the transects.



Over many months, divers documented a decline in the condition of stony corals, including this large brain coral (*Colpophyllia natans*), pictured here at Tektite reef, from healthy in August 2005 (top) to bleached in September 2005 (middle). In December 2005 this coral head began to recover from bleaching, but disease, visible as the bright white skeleton (bottom), attacked the top of the head.

as the result of analyzing historical mean water temperatures in U.S. Virgin Islands waters and detecting significant increases. Monitoring network staff understood that with higher seawater temperatures, coral bleaching, or the discharge of the coral animal's symbiotic plant cells, or zooxanthellae, might reduce the coral's ability to survive because of decreased internal food production. In this case an increase in water temperature was the assessment point that resulted in closer evaluation of coral reef resources.

Assessment points could become important management tools for alerting park managers to changes that require intervention on their part to preserve park resources.

More frequent monitoring allowed network staff to document a coral bleaching event that affected more than 90% of the stony corals. It also revealed that recovery and disease transmission rates varied by coral species and colony shape. Staff documented the widespread presence of coral disease, which unfortunately ravaged the already weakened corals, and the subsequent mortality of more than 50% of the live coral cover at the monitored reef sites. Management practices that could alleviate this loss throughout the two park units are not available yet.

Assessment points may require different management actions and need to be addressed early in park planning. For example, some assessment points may trigger an administrative action (e.g., no new permits issued for backcountry access), and others may require outreach to educate people in the region to help mitigate an impact (e.g., water conservation during a drought, or no ground fires permitted during high fire danger). Many other assessment points, including increased water temperatures in the U.S. Virgin Islands, may call for expanded monitoring, which could include examining variables that may help to better understand the problem, more frequent monitoring to ensure documentation of a highly dynamic event, and broader spatial-scale monitoring to document spread rates or the extent of the problem. Any management response may require lengthy public review, so management should consider how to address regulatory compliance requirements when changes in management activities are dictated by crisis situations.

Developing assessment points without a complete understanding of the natural variability of vital signs necessitates concerted effort. Science and the expertise of NPS professionals help determine when increased monitoring is necessary. As the National Park Service continues to gain experience in monitoring, assessment points could become important management tools for alerting park managers to changes that require intervention on their part to preserve park resources. ■

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Understanding hydrologic links between “river prairies” and other threatened riparian resources of the Cumberland Plateau

By Nora Murdock, Jim Hughes, and Robert Emmott

RANKED AS GLOBALLY IMPERILED BY THE NATURE

Conservancy, “river scour prairies”—a unique riparian vegetation type endemic to the Cumberland Plateau of Tennessee and Kentucky—occur on open, flood-scoured exposures of bedrock, cobble, and gravel along large rivers in the Cumberland River watershed. Also called Cumberlandian cobble bars, fewer than 500 acres (200 ha) of this habitat type remain in existence; the best examples are at Big South Fork National River and Recreation Area and Obed Wild and Scenic River.

Typically thick with prairie grasses and flowering herbs, river prairies share many characteristics with the tallgrass prairies of the American Midwest. Whereas fire is the dynamic force sustaining midwestern prairies, in the bottom of the deep river gorges of the Cumberland Plateau the ecological driver is water. Raging floods wash over these habitats on multiple occasions each year, scouring out species that are not adapted to disturbance, including most trees and other woody species. Grasses, herbs, and some low shrubs thrive under these punishing conditions. Several extremely rare plants, some that grow nowhere else, also flourish in these riparian prairies. In addition, two federally listed species, Cumberland rosemary (*Conradina verticillata*) and Virginia spirea (*Spiraea virginiana*), and several dozen other globally or regionally rare plants grow here.

Alternating layers of Pennsylvanian-age sandstones and shales dominate the surface geology on the Cumberland Plateau. These rocks have very low permeability, so rainfall penetration into the subsurface is limited, especially in areas of steep topography. Consequently streamflow responds rapidly to storm events. In the steep-walled gorges of Big South Fork and Obed, base flows following storms can increase from 100 cubic feet per second (2.8 m³/s) to 6,000 cubic feet per second (170 m³/s) in a matter of hours. This rapid increase in water volume and velocity produces pronounced scouring of the streambed and associated riparian areas. These powerful floods, which flush nutrients and sediments through substrates occupied by mussels and other aquatic fauna sensitive to siltation, are essential for the survival and renewal of the cobble bars and the associated aquatic community.

The hydrologic forces that create the upland portions of the cobble bars also sustain prime underwater



Highly resistant sandstone cliffs, rising 500 feet (150 m) above the floodplain, flank the rivers of the Cumberland Plateau. In these steep-walled gorges, heavy rainfall can drastically raise river flow rates within hours of a storm. Resulting floods are crucial to the long-term survival of the rare, prairielike, cobble bar communities along the rivers' edges.

habitat for a diverse freshwater mussel community. As one of the best and last remaining refuges for freshwater mussels in the Cumberland River watershed—an 18,000-square-mile (46,620 sq km) region that stretches from the western slope of the Appalachian Mountains to the mouth of the Ohio River—the Big South Fork of the Cumberland River provides habitat for 26 mussel species, including 7 that are federally endangered or threatened. Freshwater mussels are essentially sedentary creatures that feed by filtering nutrients from the water column; they are extremely vulnerable to changes in flow and water quality.



(Top) NPS staff and cooperators sample freshwater mussels at Big South Fork National River and Recreation Area, one of the last refuges for many rare mussel species. Although 26 species presently inhabit these waters, in the early part of the 20th century more than twice that number lived in the river. The best mussel beds are frequently adjacent to cobble bars.

(Bottom) Appalachian Highlands Network cooperators and staff monitor vegetation of river prairies. The best examples of this globally imperiled habitat are within Big South Fork National River and Recreation Area and Obed Wild and Scenic River.

The extraordinary aquatic systems of the Obed and Big South Fork, thought to have been decimated by unregulated pollution and mining in the early to mid-1900s, are showing encouraging signs of resilience. Significant improvements in water quality and the associated recovery of some aquatic fauna have occurred over the last 30–40 years since establishment of these National Park System areas. These habitats are responding to reclamation of abandoned mines and reduction in active mining within the Cumberland River watershed. Based on retrospective analyses of water quality data conducted by the Appalachian Highlands Network and U.S. Geological Survey, water quality trends in these two river parks appear encouraging. Also, results of recently completed fish inventories, compared with

Powerful floods ... are essential for the survival and renewal of the cobble bars and the associated aquatic community.

legacy data from fish surveys conducted 25 and 40 years ago, reveal dramatic increases in fish diversity.

Changes in river flow regimes due to upstream water withdrawals and water pollution threaten the continued survival of cobble bar and aquatic communities. The Big South Fork watershed is the site of the majority of past and present coal mining in Tennessee. Acidic drainage from abandoned mines, and contaminants and siltation (including coal particulates) associated with current mining, affect water quality. Moreover, with rising coal prices, companies are proposing new areas for mining, including 53,000 acres (21,450 ha) in the headwaters of the Big South Fork watershed. Oil and gas wells, water withdrawals for municipal and industrial use, and erosion-related sedimentation as a result of soil-disturbing activities, such as development in and adjacent to National Park System lands, also affect water quality and quantity.

In order to detect abnormalities in succession patterns and species composition resulting from hydrologic changes, in 2005 the Appalachian Highlands Network began monitoring vegetation structure and composition on the cobble bars, as well as population trends of selected endemic rare plants. Network investigators are also monitoring river flow rates and water quality in the Big South Fork of the Cumberland River, the Obed River, and their major tributaries. In 2007, network staff initiated monitoring of freshwater mussels and rare fish in order to detect population trends and changes in distribution. The Big South Fork and Obed rivers are strongholds for two federally listed fish species: the spotfin chub (*Erimonax monachus*) and the duskytail darter (*Etheostoma percnurum*). Continued monitoring is essential to ensure that adverse alterations to hydrology and water quality do not reverse trends in recovery of these unique riparian resources. ■

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Historical photos and modern sampling provide insights into climate-related vegetation changes in central Alaska

By Carl Roland

THE VAST LANDSCAPES OF INTERIOR ALASKA ARE

changing: large glaciers are melting and rapidly receding up valleys, ancient permafrost is degrading and turning frozen soils into soupy gelatin, woody vegetation is spreading dramatically into open areas, and boreal ponds and wetlands are shrinking. Climate data for interior Alaska show a pronounced warming trend over the past several decades. A growing scientific consensus suggests that a tide of relative warmth is stimulating many of the changes in Alaska's ecosystems. Yet the ultimate trajectory and outcome are unknown. What is almost certain, however, is that these changes will have profound consequences for all life in the Far North.

In 2005 the Central Alaska Network received a serendipitous gift of several hundred 35 mm slides, photographed from the backseat of a two-seater airplane in 1976. The donor, Dr. Fred Dean (professor of wildlife biology at the University of Alaska, Fairbanks), and his graduate student, Debbie Heebner, used these photographs to help produce the first land-cover map of Denali National Park. Central Alaska Network staff scanned the slides at high resolution, entered the locations of the photos into a Geographic Information System, and printed hard copies of the slides along with location maps. Then, from a helicopter, the original photographs were repeated as closely as possible. Now examined and analyzed, these photo pairs are a treasure trove of information about visible vegetation changes over the last 30 years.

The magnitude of the observed changes in many of these photo pairs was surprising. The primary types of changes were (1) expansion of spruce into formerly treeless areas, (2) invasion of open wetland areas by woody vegetation, and (3) widespread colonization of formerly open floodplains and terraces by vegetation. In many cases these changes appear directional; that is, they represent a qualitative shift in the landscape mosaic, not simply a shift in vegetation due to succession.

The repeat photo pairs provide dramatic visual evidence of recent vegetation changes. Understanding and responding to these changes requires more rigorous and detailed information. To gather the necessary data, the Central Alaska Network is implementing intensive, landscape-scale monitoring of vegetation across the three parks in the network. Monitoring according to



From 1976 (top) to 2005 (bottom), white spruce trees (*Picea glauca*) colonized a sub-alpine terrace along the upper Savage River in Denali National Park and Preserve. This photo pair highlights an example of the ongoing replacement, presumably permanent, of one vegetation community by another. Over the past 30 years many such examples appear to have impacted park landscapes.

this design began in Denali National Park and Preserve in 2001, in Yukon-Charley Rivers National Preserve in 2006, and in Wrangell–St. Elias National Park and Preserve in 2007. These units comprise 21.7 million acres (8.8 million ha), or 25% of the land area of the U.S. National Park System. The goals of this program are to detect and quantify vegetation changes like those captured anecdotally by repeat photography, and



The rapid invasion of trees and shrubs in this area of open sedge meadow had begun by 1976 (top) but was nearly complete by 2005 (bottom). This wetland, near Corner Lake in the northern lowlands of Denali National Park, had likely supported only open sedge meadow for centuries before the recent invasion by woody plants.

The repeat photo pairs provide dramatic visual evidence of recent vegetation changes.

to document the dimensions and ecological consequences of these changes using reproducible, statistically rigorous protocols.

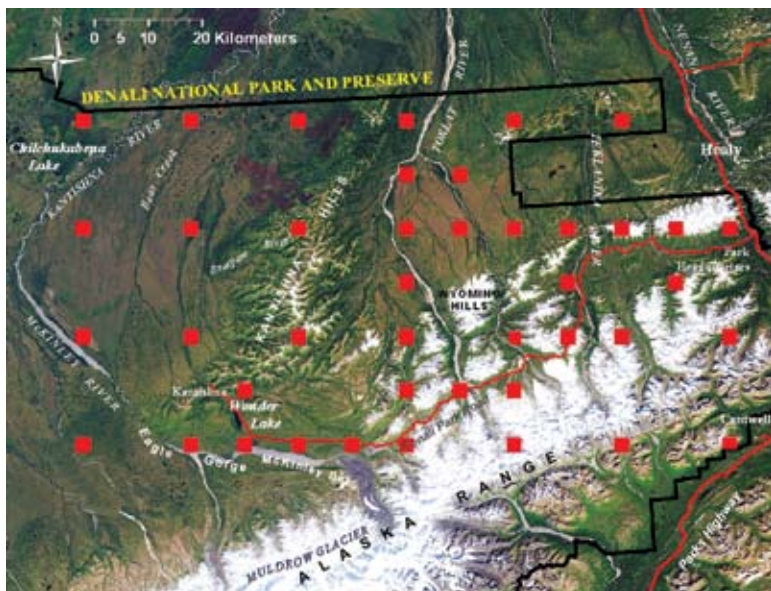
The Central Alaska Network has established a sampling design based upon a multistage systematic grid for detecting changes at individual sample plots and across park landscapes. At each plot, network ecologists measured and recorded the types and abundances of vascular plants, mosses, and lichens; dimensions and locations of all trees; and physical attributes, including those from soil samples. Network staff also collected cores from trees at the perimeter of the permanent plots and marked the center of each plot with a monument and mapping-grade Global Positioning System point. Subsequent sampling, to be conducted every seven years, will allow detection of trends in the vegetation cover at multiple nested spatial scales.

With nearly 500 permanent vegetation plots installed to date in Denali National Park and Preserve, network ecologists are already learning a great deal about vegetation-landscape relationships from these data. This work has revealed new information regarding the distribution and diversity of vascular plants across the landscape. For instance, across all spatial scales, the average species richness of plant communities increased dramatically with increasing elevation into the high alpine zone of the park.

Alpine areas also supported the greatest diversity of rare and endemic plants. The data offer an early warning of potential threats to plant conservation: with continued warming, woody vegetation will increasingly invade alpine tundra, thereby displacing these highly diverse plant communities. These data are a single strand in a multifaceted monitoring program that should allow detection, understanding, and management of dramatically changing landscapes in interior Alaska. ■

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(Above) The vegetation monitoring program for the Central Alaska Network uses a two-stage systematic grid design wherein mini-grids (red squares), consisting of 25 (200 sq m [2,153 sq ft]) sample plots arranged in a grid pattern of five rows of five plots spaced 500 m (1,640 ft) apart, are themselves located on a macro-grid of points spaced 10 km (6.2 mi) or 20 km (12.4 mi) across the park landscape. Investigators record a full suite of physical and biological characteristics at each sample plot.

Understanding biological diversity of nunataks in southwestern Alaska

By Amy E. Miller

NUNATAKS ARE EXPOSED MOUNTAIN RIDGES OR peaks encircled by glaciers. In Alaska these features occur primarily in the ice-covered areas surrounding the northern Gulf of Alaska. As islands in a sea of ice, nunataks are of interest to biologists because of their geographic isolation and their potential to support species that may have survived the Last Glacial Maximum, approximately 20,000 years ago. In addition to harboring regionally or globally rare species, these high-elevation nunatak communities may be sensitive to fluctuations in climate. As a result, they may serve as early indicators of environmental change. For these reasons the Southwest Alaska Network selected nunataks as a vital sign for monitoring.

Glaciers are an icon of the Southwest Alaska Network, which includes Kenai Fjords National Park, Lake Clark National Park and Preserve, Katmai National Park and Preserve, Aniakchak National Monument and Preserve, and Alagnak Wild River. According to a study by USGS geologist Bruce Molnia (*Global and Planetary Change* 56 (2007):23–56), from the late 19th to early 21st century all 11 mountain ranges and three islands that currently support glaciers in Alaska have experienced significant glacier retreat, thinning, or stagnation, especially at lower elevations. Whether reductions in ice cover are occurring at higher elevations and leading to changes in community composition on nunataks is uncertain.

Nunataks, such as this site on the northern Harding Icefield in Kenai Fjords National Park, are of ecological interest because of their geographic isolation and potential to support species that may have survived the Last Glacial Maximum.





A site adjacent to Tuxedni Glacier in Lake Clark National Park and Preserve serves as a long-term monitoring plot for the Southwest Alaska Network. Staff, including ecologist Amy Miller (shown here), and cooperators conducted a vascular plant inventory of this and 10 other nunatak sites in 2005.

The monitoring of nunatak communities may increase scientists' understanding of how once-isolated populations of rare plants respond as nunataks increase in size or become contiguous with larger ice-free regions.

In order to document the baseline condition of nunatak communities, the Southwest Alaska Network, in cooperation with the Alaska Natural Heritage Program, conducted a vascular plant inventory on 11 nunataks in Kenai Fjords National Park and Lake Clark National Park and Preserve in 2005. An unusually high number of species, including seven species of conservation concern, characterized 2 of the 11 sites. Though widespread in western North America, several of these rare taxa are known from very few sites within the state. Although these plants are not in danger of extinction globally, they are of critical conservation concern in Alaska because they often occur at the edge of their range or are otherwise genetically isolated. One such species, Lemmon's rockcress (*Arabis lemmonii*), ranges from British Columbia to Alaska and east to Colorado, but is known from only a few locations in Alaska and the Yukon. Botanists identified this plant at Lake Clark National Park approximately 345 miles (555 km) from the nearest known collection site in Wrangell–St. Elias National Park and Preserve. Six of the seven rare species, including Lemmon's rockcress, occur predominantly on old, unglaciated terrain in Alaska, suggesting that these nunatak sites may support a relict flora from the Last Glacial Maximum.

In addition to inventorying the vascular flora, Southwest Alaska Network staff established long-term monitoring plots at each nunatak site to document changes, if any, in the structure and composition of these plant communities over time. Investigators will revisit these sites every 5 years for the next 10–15 years, and every 10 years thereafter. During the initial inventory, staff and cooperators observed mountain goats (*Oreamnos americanus*) and smaller mammals, for example hoary marmots (*Marmota caligata*) and voles (*Microtus* spp.), at several of the nunataks; the movement of the larger mammals, along with that of birds, likely aids in seed dispersal. Although most sites supported alpine communities that are characteristic of the region, at least one site in Kenai Fjords appeared to be transitioning from an alpine snowfield community to a more temperate, low-elevation coastal community, suggesting a decrease in snow cover or an increase in the length of the growing season. Another site, at Lake Clark, lacked the rich lichen community found at many other sites, as ash fall from the 1989–1990 eruption of Mount Redoubt had impacted this site.



Lemmon's rockcress (*Arabis lemmonii*) is a rare member of the mustard family. This species, which investigators found on a nunatak in Lake Clark National Park and Preserve, is known from only a few locations in Alaska and the Yukon.

In addition to floristic studies in these high-elevation areas, network staff is developing an array of weather stations to monitor long-term climate fluctuations and is using remote sensing to monitor changes in glacial extent. Cooperators at NASA–Goddard Space Flight Center in Greenbelt, Maryland, have documented an overall reduction in glacier area in Kenai Fjords over the last 30 years and a 3.6% reduction in ice extent from 1986 to 2000 alone. In 2007, cooperators will begin an analysis of glacial extent for a similar 30-year period at Lake Clark. Using aerial photos from the 1950s and 1990s and IKONOS imagery acquired since 2005, network staff will also examine changes in nunatak area across the Southwest Alaska Network. Given the potential for continued glacial recession in southwestern Alaska, the monitoring of nunatak communities may increase scientists' understanding of how once-isolated populations of rare plants respond as nunataks increase in size or become contiguous with larger ice-free regions. As a result, the National Park Service may be better able to maintain the integrity of these communities, even as their boundaries shift. ■

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Environmental and ecological implications of aggradation in braided rivers at Mount Rainier National Park

By Scott R. Beason and Paul M. Kennard

IN NOVEMBER 2006 A MAJOR STORM DROPPED

nearly 18 inches (46 cm) of rain in 36 hours at Mount Rainier National Park, Washington. This event caused severe park-wide damage, but the resulting flood was not entirely to blame for the destruction. The geologic setting, physical characteristics of the rivers, and injudicious placement of park infrastructure made the devastation inevitable.

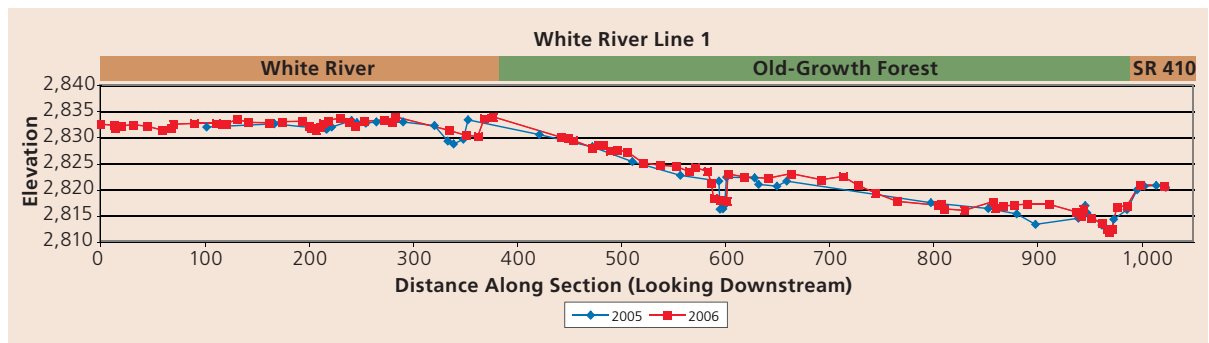
At Mount Rainier, glacially fed braided rivers radiate outward from the 14,410-foot (4,392 m) volcano. These streams carry materials ranging in size from silt to boulders. As gradients decrease away from the mountain, rivers deposit their sediment loads. The height of the river channels rises while streambanks and floodplains remain at their present elevations. Through this process, called aggradation, rivers at Mount Rainier National Park have been inexorably increasing in height over time.

Exact rates of river aggradation in the park were unknown until a 2006 study, which incorporated survey data from 1997 and 2005. Using 1910 longitudinal profiles and historical topographic maps, the National Park Service and cooperating scientists compared current and earlier rates of aggradation, focusing on river areas near popular visitor destinations and primary park infrastructure. Investigators surveyed and created cross sections of current river channels, which they analyzed using Geographic Information System (GIS) software. Depending on the channel slope and confinement, the background aggradation rate of braided rivers at the park is approximately 6 to 14 inches (15 to 36 cm) per

decade. At areas in the park with recent debris flows, however, aggradation is much higher. For example, during a single event, approximately 6 feet (1.8 m) of material was deposited over an area of 107,000 square feet (9,940 m²) in the Nisqually River above Longmire, a primary park visitor and work area.

In many places, park buildings and roads are literally within aggrading rivers, and several locations in the park are below rivers (i.e., one walks uphill to get to the river channel). For instance the bed of the White River is as much as 16 feet (4.8 m) above the surrounding area through which a major highway, State Route 410, passes. Also, the main village at Longmire is 29 feet (8.8 m) below the Nisqually River. This juxtaposition contributed to the majority of the dramatic damage to the park infrastructure following the November 2006 flood. However, the flooding did not “clean” the system of aggrading material, but rather added to it.

As a result of this study, investigators have identified an increasing rate of aggradation in the park over the last 30 years, and attribute this escalation to global climate change. As temperatures increase, glaciers in the park recede. When the ice retreats, it no longer buttresses the steep, unconsolidated lateral moraines and outwash plains, making them prone to landsliding. These types of failures supply rivers with tremendous amounts of sediment and have caused several recent debris flows. Additionally, the results of this study revealed a relationship between suspended sediment load and air temperature at the park. As air temperature increases, sediment provided to the rivers



This cross section shows the elevation of the White River as compared with State Route 410. The river is shown from 0 to 350 feet. The remaining cross section includes an old-growth forest and State Route 410. At this point the river is 2,832 feet (863 m) above sea level (asl), while the road is 2,820 feet (860 m) asl, or about 12 feet (3.7 m) below the river. Just downstream from this location, the difference is 16 feet (4.9 m).

Exact rates of river aggradation in the park were unknown until a 2006 study.

increases exponentially, in the long and short terms. This is scientifically important, because the measured increased aggradation is consistent with climate change. It is also important for park planning because as the global climate continues to warm, more material will be supplied to river channels, further increasing the rate of aggradation.

Though this research has greatly illuminated the process of riverbed aggradation, researchers have just begun to understand the ecological impacts on channel form, aquatic habitats, and riparian succession. Therefore the current research priority is to understand the effects of aggradation on floodplain ecosystems and dynamics. Investigators want to be able to characterize and describe the effects of aggradation on subsurface and surface water flows, channel patterns (i.e., braided, meandering, and straight), diversity and persistence of habitat types, and spatial and temporal dynamics of floodplain vegetation.

Despite many remaining questions, some trends are emerging. Based on observations where the channel bed has aggraded 38 feet (12 m) in the last 100 years, the water table has risen with the bed and the river has not disappeared (i.e., running subsurface below the new sediment deposits). This occurs despite the relative coarseness of the riverbed sediment (coarser sediments are relatively porous and generally support intergranular flow). As a result, fish can still navigate the river, even during low water flow. Additionally, in the last 10,000 years, coniferous forests have been encroaching on valley bottoms, gradually constraining the potential zone of river-channel migration. Recent flooding deposited copious amounts of sediment in these old-growth forests, killing acres of trees and drastically slowing and possibly stopping the rate of valley floor reforestation.

Mount Rainier National Park is an active, dynamic geologic environment capable of dramatic change over short time periods. Most people think of volcanic activity as the principal agent of change in the park. However, as recent flooding and the results of this study show, rivers, by way of aggradation, modify the environment in extreme ways and will continue to present challenges for park planning and development in the years to come. ■



(Top) The braided rivers at Mount Rainier National Park have been aggrading at increasing rates over the past 30 years. Added to the overall aggradation process was sediment deposited during the 2006 flood. Before the flood the space between river level and the bridge over Tahoma Creek was double the amount shown here.

(Bottom) Some reaches of the White River have aggraded to the point of being above the surrounding landscape, including park infrastructure.

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Analyzing the bison genome of Department of the Interior herds

By Natalie Halbert, James Derr, Ron Hiebert, and Peter Gogan

FROM 1997 TO 2002 THE NATIONAL PARK SERVICE and the U.S. Fish and Wildlife Service collected blood, hair, or tissue from 2,260 individual American bison (*Bison bison*) and shipped these samples to Texas A&M University for analysis. Investigators at Texas A&M examined mitochondrial DNA and 49 polymorphic markers (microsatellite DNA) dispersed throughout the bison genome. Now these results are impacting the long-term management of this species and changing the face of bison conservation in North America.

American bison reached an estimated population of 25–40 million on the Great Plains at the beginning of the 19th century. By the late 1820s, however, bison in North America were already in decline as a result of both natural and anthropogenic factors, including the introduction of horses and other exotic animals that increased hunting efficiency and introduced exotic diseases. Moreover, advancements in firearms and transcontinental rail transportation facilitated uncontrolled hide hunting by both aboriginal and Euro-American hunters, which contributed to the rapid population crash of the late 1800s. At the apparent brink of extinction, fewer than 1,000 American bison, including both the plains and wood bison types, existed in the world. Between 1873 and 1904, citizen and government protection of six captive herds and the remnants of two wild herds in the United States

(Yellowstone National Park) and Canada (Wood Buffalo National Park) saved the species from this precipitous decline. From these herds a combined total of fewer than 500 bison served as the foundation stock for all bison in existence today. More than 500,000 bison inhabit North America now; most are raised as live-stock in private herds. The U.S. Fish and Wildlife Service and the National Park Service manage approximately 6,000 bison in 11 “conservation herds.”

The U.S. Department of the Interior (DOI) Bison Conservation Working Group—a consortium of government researchers and managers—has met annually since 1997 to share information about bison management techniques, animal health, policy, genetics, and demographics. This group, which met most recently in 2006 at Fort Niobrara National Wildlife Refuge in Nebraska, recognizes that genetic data are needed to inform management practices, such as whether to manage the DOI herds as separate populations or as a single meta-population. To address this and other conservation issues, managers need to first establish an understanding of the current genetic makeup of these herds, including present levels and patterns of genetic variation within and among herds, the effects of various culling practices on the maintenance of genetic variation, and the level of domestic cattle DNA found in the DOI bison herds.



Federal and university researchers have recently directed much effort at understanding the genetic architecture of American bison (*Bison bison*) herds, which collectively represent some of the most extensive population genetic investigations of any wildlife species.

The small sizes of the DOI bison herds are a major challenge for maintaining genetic variation.

With funding from the U.S. Geological Survey Biological Resources Discipline, Natural Resource Preservation Program, and various U.S. Fish and Wildlife Service sources, the National Park Service and the U.S. Fish and Wildlife Service entered into cooperative agreements with Texas A&M University to conduct genetic studies that would answer management-related questions. Drs. Joe Templeton and James Derr advised the project; Ph.D. candidate Natalie Halbert served as the primary investigator. Additionally, Dr. Guiming Wang (Colorado State University) and Dr. John Gross (NPS Inventory and Monitoring Branch) conducted simulations to prescribe management practices that would maintain genetic health of the DOI herds. Dr. Ron Hiebert and Dr. Peter Gogan served as the NPS and USGS coordinators respectively.

Detailed evaluation of these data indicates that DOI bison herds contain moderate to high levels of genetic variation and show no signs of inbreeding depression. Herd histories explain much of the patterns of variation and relatedness among herds. Multiple lineages that trace back to the original founding herds are represented across the DOI herds, resulting in some of these populations possessing unique genetic characters.

Most of the ranchers involved in saving bison from extinction in the late 19th century were interested in producing hardier breeds of cattle, and records indicate many were directly involved in efforts to hybridize bison and domestic cattle. The two species do not naturally interbreed, but ranchers produced fertile crosses in captivity. Both historical and recent hybridizations between bison and domestic cattle have led to genetic introgression—unnatural introduction of domestic cattle DNA into the bison genome—which significantly complicates bison conservation efforts. Domestic cattle DNA appears in most of the private and state bison herds tested to date. By contrast, less than 1% of the genome of bison in DOI herds is derived from domestic cattle, and no evidence of domestic cattle introgression occurs in bison from either the Yellowstone or Wind Cave herds.

Human-induced environmental and landscape changes have led to the existence of relatively small, isolated populations of many large mammals. The small sizes of the DOI bison herds are a major challenge for main-

taining genetic variation. Using the genetic data from Texas A&M University, Wang and Gross found that in excess of 1,000 breeding individuals are necessary to maintain present levels of genetic variation over the next century. Among DOI bison herds, only the Yellowstone National Park herd boasts this size. In addition to increasing population sizes as much as possible, the simulations by Wang and Gross suggested several management changes to reduce the overall loss of genetic variation, such as increasing the generation time by culling the young of the year.

Movement of animals among herds is another management alternative to augment or maintain levels of genetic variation. However, managers must carefully consider this option in order to prevent the spread of wildlife diseases such as brucellosis and to maintain unique attributes found in some populations. Some herds contain evidence of domestic cattle introgression, while other herds have no historical or genetic evidence of hybridization with cattle. Therefore, managers must rigorously evaluate the perceived benefits of transporting animals among herds in light of potentially irreversible effects.

The federal herds have a significant role in the long-term preservation and conservation of bison as a distinct species. These herds serve as the best source of animals for starting satellite populations and restoring plains bison to areas where they can roam freely and be subject to natural selection. The development and implementation of management policies by managers of federal herds may well serve as a model for long-term conservation of other wildlife species. ■

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Determining habitat use and abundance of piping plovers at Padre Island National Seashore

By Michelle Havens and Kristie Landaberde

AT LEAST 10% OF THE WORLD'S POPULATION OF piping plovers (*Charadrius melodus*) migrates through Padre Island National Seashore (Texas) and uses its beach for nonbreeding habitat. Each year these small shorebirds journey thousands of miles between their breeding grounds (i.e., Atlantic coast, Great Lakes, midwestern United States, and Canada) and wintering grounds (i.e., southern Atlantic and Gulf of Mexico coasts), with documented occurrences 12 months of the year at Padre Island. In 1986 the piping plover was declared federally endangered around the Great Lakes and threatened throughout the remainder of its U.S. range. Canada's Committee on the Status of Endangered Wildlife also considers the species endangered. Although these birds have been studied extensively in their breeding grounds, very little research has been conducted to determine appropriate monitoring and protection protocols for them in nonbreeding areas, where they spend nearly two-thirds of the year.

Because the national seashore is a highly important stopover and nonbreeding area for piping plovers, park staff obtained funding to conduct research on piping plover abundance and habitat use. The study began in 2005, and resource employees conducted weekly surveys along the more than 60 miles (96 km) of the Gulf of Mexico shoreline in the national seashore. Since then, National Park Service staff has conducted more than 100 surveys, with more than 5,000 piping plovers observed. In October 2006, biologists conducted two surveys, documenting a total of 588 piping plovers, with an amazing 235 piping plovers along a 5-mile (8 km) stretch of beach during one of the surveys. Overall, more than 80% of the piping plovers were observed foraging alone near the tide line. Numbers this high are unheard of in most other nonbreeding areas. As a result of these numbers, the Western Hemisphere Shorebird Reserve Network selected Padre Island National Seashore as the first National



Biologists combine surveying, color banding, and radio-transmitter tagging in surveys of piping plover at Padre Island National Seashore. During a pilot project from August to September 2006, they banded, radio-tagged, and released two piping plovers. Though the transmitters became nonfunctional within a week, each bird was later relocated near where it had been captured. One of the birds was identified, by color bands, in the same area 32 times since shedding the radio transmitter. This is compelling evidence that piping plovers stay in particular areas of the Gulf of Mexico beach.



Though most often observed foraging alone near the tide line, here a piping plover (in the background) forages near a sanderling (*Calidris alba*). Piping plover density is greatest along the seashore's northern boundary, which is closed to vehicular traffic. Biologists have recorded 31 piping plovers per mile in this area. Farther down the shoreline, rough terrain, coarse-grained sediment, and a narrow beach make the beach unappealing to the birds.

Park System unit to be recognized as a member. Other significant factors in its selection were the ecological importance of the habitat and park staff's commitment to shorebird conservation. The national seashore is included in the network's Binational Laguna Madre Site of International Importance, which includes lands managed by Mexico, The Nature Conservancy, and the U.S. Fish and Wildlife Service.

Park biologists are working with the Canadian Wildlife Service, U.S. Fish and Wildlife Service, U.S. Army Corps of Engineers, and Virginia Tech University to share band sightings and determine survivorship and site fidelity of piping plovers migrating among breeding and nonbreeding areas. Park staff is also partnering with a variety of U.S., Canadian, and Mexican federal agencies, universities, nongovernmental organizations, and the State of Texas to prioritize significant wintering areas and management options for piping plovers along the Texas coast. Color banding and radio-transmitter tagging allow individual identification of birds and make it possible to study the dispersal, migration patterns, and life span of each bird. With approval from the U.S. Fish and Wildlife Service, the National Park Service began to capture and mark piping plovers in late 2006.

With increasing development encroaching upon the national seashore and growing interest in nonfederal

oil and gas exploration at Padre Island, this urgent research will fill an information gap and provide documentation for improving management and conservation of piping plovers throughout their range. Future studies are expected to look into shorebird disturbance and lead to such management actions as non-federal oil and gas mitigation measures, park program management (e.g., beach maintenance), and permitting for recreational activities. Plover research at Padre Island National Seashore is contributing significantly to the understanding of piping plover non-breeding habitat requirements. As a result, park staff will be able to craft guidelines for park development, provide educational opportunities beneficial to the species, and contribute to the global protection of piping plovers. Specifically, limited access and the potential for resource damage have delayed surveys on the Laguna Madre shoreline of the island, which provides excellent foraging and roosting for non-breeding piping plovers. As methods to survey the Laguna Madre shoreline are developed, the national seashore has the opportunity to host up to 20% of the world's population of piping plovers during the fall months when the population is thought to surge. ■

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Hurricane Wilma benefits mangrove forests at Everglades National Park

By Kevin R. T. Whelan and Thomas J. Smith III

WE TYPICALLY VIEW HURRICANES AS DISASTERS

that cause extensive damage, particularly to infrastructure but also to natural areas such as estuaries, beaches, and barrier islands. However, hurricanes also have ecological benefits, such as dispersing species to new areas; thinning forests, which may favor regeneration by specific species; and flushing bays. Additionally, in 2006, researchers at Everglades National Park (Florida) found that hurricanes added needed sediments to wetlands, in particular the park's mangrove forests. Along the southwestern coast of Florida, the average annual rate of sea-level rise is 0.07 inch (1.9 mm) per year; mangrove forests can keep pace with increasing sea-level rise only if an adequate sediment supply sustains the soil elevation relative to sea level. Hurricanes can provide a sudden pulse of sediment

to mangrove communities, which are critical habitat for the park's world-renowned wading bird populations—the primary reason for the establishment of the park. Mangroves also harbor threatened and endangered species (e.g., American crocodile [*Crocodylus acutus*] and West Indian manatee [*Trichechus manatus*]) and are an important nursery for many sport fish.

On 24 October 2005, Hurricane Wilma came ashore between Cape Romano and Everglades City as a category 3 storm, with sustained winds varying from 61 to 103 miles per hour (98 to 166 kph). Prior to landfall, Hurricane Wilma was the third category 5 hurricane of the 2005 Atlantic season but became the most intense hurricane on record in the Atlantic basin. The National



Mangrove forests, including the one at the mouth of the Shark River, cover more than 148,000 acres (60,000 ha) in Everglades National Park, Florida.

Oceanic and Atmospheric Administration National Weather Service Forecast Office estimated Hurricane Wilma's storm surge to be 16 to 18 feet (4.9 to 5.5 m) of water for the mangroves of southwestern Everglades National Park. As reported in *Natural Resource Year in Review—2005*, defoliation by Hurricane Wilma was so severe that researcher Thomas J. Smith expected that the mangroves would continue to die for months after the storm.

On 11 November 2005, investigators from the NPS South Florida/Caribbean Inventory and Monitoring Network and the U.S. Geological Survey sampled the storm deposit from Hurricane Wilma at a long-term soil surface monitoring site. Varying from 1.2 to 2.4 inches (30 to 60 mm) thick, the storm-deposited layer was composed of very fine marine material (1.2 to 1.6 inches [30 to 40 mm]) on top of mangrove leaf matter (0.4 to 0.8 inch [10 to 20 mm]), which hurricane winds had stripped from the trees. Deposition increased the elevation of the soil surface by about 1.2 inches (30 mm). The increase in soil surface elevation from this one hurricane was greater than the measured accumulation at the site for the previous seven years. This event deposited material that will “combat” 16 years of estimated sea-level rise. One year after Hurricane Wilma, investigators resampled the layer and found that minimal erosion (0.33 inch [8.5 mm]) had



In November 2005, investigators sampled the sediment layer deposited during Hurricane Wilma (red arrow) and the layer of green mangrove leaves stripped by hurricane winds (green arrow). Deposition during Hurricane Wilma is helping the mangrove forests keep pace with rising sea levels. The feldspar marker horizon (white arrow) is an artificial layer that investigators applied to the soil surface. It is slowly being buried in the soil column as sediment is deposited.

The increase in soil surface elevation from this one hurricane was greater than the measured accumulation at the site for the previous seven years.

occurred; approximately 68% of the storm-deposited, soil surface elevation remained. This gain keeps pace with 10 years of estimated sea-level rise. Additionally, numerous fine roots from the mangrove trees now penetrate the storm deposit.

The material deposited during Hurricane Wilma should have a beneficial impact on the overall soil elevation of the mangroves of southwestern Everglades National Park and will be an important factor for soil dynamics in the near future. Additionally, this deposit will have a lasting effect on soil nutrients and soil hydrological conductivity (how water moves through sediment). It may also change mangrove seedling recruitment and the burrowing fiddler crab (*Uca thayeri*) community. The ecological outcome of Hurricane Wilma in the mangroves of Everglades National Park will be the result of the interaction between the beneficial effect of the storm deposit on soil elevation and the deleterious impacts from large-scale tree damage and mortality. ■

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Understanding salt-marsh dieback in Cape Cod National Seashore

By Stephen Smith, John Portnoy, and Kelly Chapman

IN 2003, WHILE ASSESSING SALT-MARSH VEGETATION as part of Cape Cod National Seashore's Inventory and Monitoring Program, botanist Stephen Smith and ecologist John Portnoy discovered large areas of dead plants in a remote marsh. Subsequently, numerous dieback locations have been documented within the park, in other areas of Cape Cod outside the park boundary, and in other coastal New England states where one to three species of salt-marsh vegetation have been lost. Some biologists have called this phenomenon "sudden wetland dieback" and it has received a great deal of attention from scientists, resource managers, and the news media over the past several years. In Cape Cod National Seashore, mudflats now replace

as much as 12% of emergent marsh. In fact, Cape Cod appears to be the "epicenter" of salt-marsh dieback in the Northeast.

During the past year Smith acquired and analyzed hundreds of photographs from 1940 through 2005 and discovered that sudden wetland dieback may not be the new phenomenon it was originally thought to be. He found that progressive losses of salt-marsh vegetation on Cape Cod appear to have been occurring for several decades. However, the reasons for the phenomenon and the implications for salt-marsh ecology are a complex issue. Field observations indicate that factors such as plant debris, ice scouring, grazing geese, and



(Left) The death and disappearance of salt-marsh vegetation appear as brown or beige areas within this Cape Cod marsh.

(Below) High marsh dieback areas are conspicuous as open, brown mudflats amidst healthy lower marsh vegetation that is advancing landward.



As a complement to monitoring of salt-marsh change, a series of field experiments will be conducted in 2007 to test the hypothesis that sea-level rise and peat accumulation are primary causes of dieback in the national seashore.

soil toxicity can be ruled out as primary causes of dieback. Fungi of the genus *Fusarium* may be responsible for diebacks in southern and Gulf Coast states. Drought and snail grazing have been discussed as potential causes in Georgia and South Carolina. At Cape Cod, Smith found that the relict peat in many of the diebacks in the lower-elevation parts of marshes contained roots from *Spartina patens* and *Distichlis spicata*—species that indicate where the high marsh was when sea level was much lower. As *S. alterniflora* advances to higher ground left open by diebacks of the plants there, it gives the impression of dieback, when actually the higher ground species were the first to go. In other words, the retreat of *S. patens* and *D. spicata* from their seaward edge is exceeding the landward advance of *S. alterniflora*.

After several years of field monitoring, greenhouse experiments, and analysis of ground-level and aerial photography, a plausible explanation of salt-marsh dieback is beginning to emerge. For high marsh species it is almost always the lower-elevation (seaward) edge that is dying back. Water level recorders placed in the root zones by Cape Cod's hydrologic technician Kelly Chapman show that high marsh dieback edges are considerably downslope of the mean high tide level, which is considered the seaward limit of their ecological niche. Diebacks also occur in the low marsh; however, *S. alterniflora* losses have occurred at many different elevations between mean low and mean high tide. In general, the most severe diebacks are observed along the banks of large tidal creeks, around the edges of marsh islands, and along elevation breakpoints within the marsh that receive high wave energy. These areas correspond with a significant widening of tidal creeks and losses of marsh edges and islands over the last few decades. In addition, the long-term accumulation of extremely dense peat from the plants themselves may be contributing to a kind of natural decline. Where centuries of accumulated peat has been eroded away by waves or scoured away by ice to expose the much looser underlying sediment (primarily sand), plants are healthy and vigorous.

As a complement to monitoring of salt-marsh change, a series of field experiments will be conducted in 2007 to test the hypothesis that sea-level rise and peat accumulation are primary causes of dieback in the national seashore. Manipulation of ground elevations along the

seaward edge of high marsh dieback zones and removal of dense peat reefs in low marsh dieback zones will help national seashore scientists determine the relationship of rising sea levels and peat accumulation to vegetation loss and understand how salt-marsh landscapes are changing as a result of this process. Erosion following dieback events can have enormous implications for recovery, as sediment loss from the marsh and transport to coastal waters can impact nearshore, and potentially offshore, communities. Smith, Portnoy, and Chapman are monitoring erosion rates and hydrology at numerous locations. Initial data reveal that significant losses of elevation are occurring in dieback areas even during periods of calm weather and that certain high marsh edges are inundated more frequently by tides than previously thought.

Careful assessment of Cape Cod's salt-marsh resources has produced a wealth of information on the nature of dieback. This, in turn, has generated great interest within the larger scientific community. Three workshops have been held on the subject and partnerships are being formed with scientists and resource managers from the U.S. Geological Survey, U.S. Fish and Wildlife Service, Connecticut Department of Environmental Protection, Connecticut Agricultural Research Station, Brown University, University of Massachusetts, Marine Biological Laboratory, Massachusetts Audubon, and Massachusetts Coastal Zone Management. The development of this collaborative effort and the science that emerges from it can be directly attributed to the implementation of natural resource inventory and monitoring that will provide the basis for related management and public education. ■



Severe dieback leads to erosion along the marsh edge.

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